DECISION STRATEGIES BASED ON FORECASTS OF ALTERNATIVE WEATHER STATES

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Alternatív időjárási állapotok előrejelzésén alapuló döntési stratégiák. Két egymást kizáró időjárási állapot egyikének bekövetkezésére vonatkozó éghajlati valószínűségek, kategórikus prognózisok illetve valószínűségi előrejelzések optimális felhasználását mutatjuk be egy általános döntési helyzetben, mely két adekvát és egy kompromisszumos intézkedés közül enged választást a prognózis tartalmától és az elemi gazdasági következményektől függően. Mindhárom időjárási információ-típusra megadjuk az optimális stratégia kiválasztásának paraméteres kritériumait. E kiválasztás az éghajlati információt felhasználó három triviális stratégia esetén három, a kategórikus prognózis kilenc lehetséges stratégiájára pedig mindössze hat egyenlőtlenség megoldását igényli. A valószínűségi prognózis esetében kimutathatjuk, hogy a kompromisszumos intézkedés felhasználása nem minden gazdasági paraméter-együttesre ad jobb stratégiát, mint a két adekvát intézkedés közötti határ-valószínűséget optimálisan kiválasztó stratégia. A paraméteres stratégia-kijelöléseket a *Péczely*-típusokhoz kapcsolódó meteorológiai példával is szemléltetjük.

Optimal application of climatic probabilities, categorical and probabilitic forecasts of two alternative weather states is demonstrated in a generalized decision situation allowing the choice between two adequate and one compromizing operations in connection with the content of the forecast and the elementary financial consequences. Criteria for choosing the optimum strategy expressed by parameters of the decision model are presented for the three types od weather information. This choice demands the solution of three inequations in case of the three possible strategies based on climatic information and only six inequations for the nine strategies applying categorical forecasts. In case of probabilistic forecasts it is demonstrated that the application of a compromizing operation improves the best strategy with the two adequate operations not for all possible ensembles of the economical parameters. Parametrized strategy specifications are illustrated in a meteorological example connected with macrosynoptic types defined by *Péczely*.

1. Introduction

Weather forecasts are generally applied in economical decisions mainly based on subjective reflections of the likely gains or losses in connection with the possible operations, the external conditions (eg. weather in our case), the a priori probabilities of the conditions, the elementary financial consequences of each operation influenced by the actual external condition, the decision criterion and strategies to fulfill this criterion (ANDERSON et al., 1977). The appearance of subjectivity in the decision is generally caused by the complexity of real decisions and the limited accuracy in estimations of the elementary consequences. Nevertheless there are some simple operative decisions where the main uncertainty is the weather condition and quantitative decision models are applied.

The uncertainty of future weather conditions can be decreased to some extent studying the a priori probability of the weather conditions, i.e. the climate of the area in question, which in practice can be approximated by the statistic of weather elements from the past. (The detected and projected climate variations can generally be neglected in case of activities influenced by daily weather conditions but they are worth taking into consideration if the process is governed by longer time averages eg. monthly means - MIKA and BONCZ, 1983, KOPPANY, 1987 - .)

A generally more efficient estimation for the expected weather condition is the use of a continous stream of specialized forecasts (i.e. processed and designed just for this decision) that can also integrate the information on the initial conditions of the atmosphere. However there is a limitation also int. he second alternative namely the uncertainty of the forecast-skill which is mainly caused by the effort of forecasting centers to assimilate the maximum of the attainable information and the experience of the experts that a combination of objective methods with the subjective (synoptical) experience gives better forecasts than any objective routine alone. Disadvantages of this attitude are the possible trends and fluctuations in the amount of the utilized information before releasing the forecasts and the appearance of subjectivity in the forecasts. These circumstances make the forecast-skill nonstationary in time. This uncertainty of the actual forecast can not be resolved by specification of a generalized numerical character reflecting the proportion of succesful forecasts (e.g. in percents) because it does not determine the necessary input parameters of the decision-model unequivocally. The decision-maker therefore needs the two-dimensional probability distribution of the forecast-reality ensamble which in case of discrete elements can be expressed in the form of a contingency table (*KOPPANY, 1975*).

In this connection some methods not applying the complete set of attainable information but achieving a reasonable and strictly stationary skill can also be useful in several simple decision problems. (Nonstationarity connected with the diurnal or annual cycles can usually be satisfactorily excluded by grouping the same phases into separate samples.)

A possible way to this kind of forecasts can be the combination of the conditional probability distribution in different macrosynoptic types with the numerical forecast of pressure field applying a recognition method of macrotypes. For Hungary the macrosynoptic classification derived by *Péczely* seems to be the most promising for this purpose because of its little areal coverage [see *PECZELY (1957,1961,1983)* or *KAROSSY (1987)* for further investigations with the typization].

In *Section 4* we show an example for assimilation of forecasts based on these macrotypes: the case of three operations and two alternative weather states. The formulae for finding the optimum strategy in case of categorical and also of probabilistic forecasts - being the main results of this study - are derived in *Section 3*, while the decision problem and the case of climatic information (ie. absence of the specialized forecasts) are designed in *Section 2*.

2. The decision problem and use of climatic information

Let us assume that our economical activity is determined by two conditions of weather X_1 and X_2 (eg. the existence or lack of precipitation, the exceeding of a threshold value in a continous weather element like temperature or wind speed, etc.). Both possible conditions involve the ad equate operations O_1 and O_2 (eg. preventive measures or doing nothing), but there is a thiird operation O_c (eg. making some protection possible if X_1 takes place) as a result of a compromise between the two possible conditions. The a priori (climatical) probability of condition X_1 is P while the probability of condition X_2 is $(1 - P)$.

We also have consequences of each operations which are functions of the weather condition realized as presented in *Table Ia*. Now and in the following we calculate the mean loss (or loss comparing to some idealistic gain) assuming that the decision criterion is the minimization of the loss in a long time average.

A lower estimation ofthe mean loss is

$$L_{min} = AP + B(1 - P) \qquad /1/$$

which by all means appears independently of the forecast-skill or the decision strategies. As our aim is to determine the optimum strategy we can leave out $L_{*,*}$ in each term of our calculations (*Table Ib*). A further reducing of our calculations is possible inthe following way: We can assume without any limitation of generality that

$$d > a \qquad /2/$$

in the loss-matrix, because it only makes the usage of indices unambigous. On the other hand the essence of the compromizing operation is that

$$b < d \qquad /3/$$

and

$$c < a, \qquad /4/$$

therefore we can operate with a transformed loss-matrix (*Table Ic*), where

$$a' = \frac{a}{d} \qquad /5/$$

$$b' = \frac{b}{d} \qquad /6/$$

$$c' = \frac{c}{d} \; . \qquad /7/$$

Table I

Reduction of the loss-matrix from its complete version expressed in absolute units (*Ia*) to the net losses in relative units (*Ic*) through the net version in absolute units (*Ib*).

	O_1	O_c	O_2
X_1	A	A+b	A+d
X_2	B+a	B+c	B

Ia

	O_1	O_c	O_2
X_1	0	b	d
X_2	a	c	0

Ib

	O_1	O_c	O_2
X_1	0	b'	1
X_2	a'	c'	0

Ic

In *Table Ic* $0 < a' > 1$, $0 < b' < 1$ and $0 < c' < 1$. In order to simplify our calculations we omit the ( )'indications in the following but it is worth mentioning that everywhwere the last version ofthe loss-matrix (*Table Ic*) is bearing in mind.

Having only the a priori (climatical) information on the weather condition the decision-maker has to choose one operation which is the most promising according to his decision criterion (ie. the minimization of the average loss in our case). For the three possible strategies (operations) the average losses are

$$L(O_1) = (1 - P)a \qquad /8/$$

$$L(O_c) = Pb + (1 - P)c \qquad /9/$$

$$L(O_2) = P \qquad /10/$$

To choose the best strategy from the three possible ones we have to solve three inequalities presented in *Table II* together with the specification of the optimum strategy in case of possible logical values of the inequalities (ie. true or false). Although these inequalities are not independent of each other, none of them can be omitted if all possible values of the P, a, b and c parameters can be realized. On the other hand in the case of a given set of parameters two inequalities are enough for finding the best strategy but we can not establish a priori which the redundant one is.

Table II

The key inequalities and decision rules in case of apriori (climatical) information. In case of (+) the in-equality should be true and in case of (-) false in order to make the marked operation being the optimum. Mark (0) means that the value of the inequality is indifferent. (Parameters a, b and c are defined in *Table Ic* but the accent marks are omitted.)

	Inequalities	O_1	O_c	O_2
I.	$\frac{a-c}{b} < \frac{P}{1-P}$	+	+	0
II.	$a < \frac{P}{1-P}$	-	0	+
III.	$\frac{c}{1-b} < \frac{P}{1-P}$	0	-	-

3. The decision problem with special weather forecasts

Two different weather forecast syntaxes are possible. The first one contains a categorical statement about the weather in future (X_1^* or X_2^*) while the second possibility is to give the π_1 probability of condition X_1 (or $\pi_2 = 1 - \pi_1$ for X_2). The more sophisticated version is the second one but its economical potential can be effectively realized only if the economical parameters are well-known and the forecast is undistorted ie. the notified probability is really equal to the true one. In order to assure this criterion in the following we also assume that both forecasting syntaxes are results of purely objective methods. In addition to it we also neglect the costs of getting the forecasts.

Calculations presented below are not new in mathematics of economical decisions but likely in literature on application of meteorological forecasts in decisions. For example in the monography by ZHUKOVSKY (1981) containing several decision problems with quite numerous references from different countries there is not a complete solution of the problem neither for categorical nor for probabilistic forecasts in case of the situation with two adequate and one compromizing operations. The only issue (BELENKY et al., 1974) for the categorical case of our *Section 3.1* with two strict limitations of generality. The first one is that the percentage of good forecasts is the same for both alternative weather states and the second one is that the probability of each state is equal to the frequency of its forecasting. At the same time in the case of probabilistic forecasts the optimity of the strategy-type containing three operations is assumed to be optimal a priori which can be not the case as it is demonstrated in *Section 3.2*.

3.1 Categorical forecasts

The skill of weather forecasting in case of categorical syntax (stating X_1^* or X_2^*) can be designed as a contingency matrix presented in *Table II*. The elements of this matrix are formed as products of the a priori probabilities and the conditional probabilities [($p_1 = P(X_1^* | X_1)$ and $p_2 = P(X_2^* | X_2)$] of succesful forecasts presuming that the given weather condition takes place. The sum of the four matrix-elements is equal to *1*.

Having 3 possible operations and receiving a two-category forecast the decision-maker can choose from nine possible strategies including the three a priori strategies (ie. neglecting the forecasts) presented in *Section 2*. The nine strategies are demonstrated in *Table IV* together with the average losses derived by appropriate production of matrices presented in *Tables III* and *Ic*.

Table III

The matrix of forecast-skill for categorical forecasts: $p_1 = P(X_1^* | X_1)$, $p_2 = P(X_2^* | X_2)$

	X_1^*	X_2^*
X_1	$p_1 P$	$(1-p_1)P$
X_2	$(1-p_2)(1-P)$	$p_2(1-P)$

Table IV

The possible 9 strategies and their average losses in case of categorical forecasts

Strategies	X_1^*	X_2^*	Average losses
1.	O_1	O_1	$(1-P)a$
2.	O_1	O_2	$(1-p_2)(1-P)a + (1-p_1)P$
3.	O_1	O_c	$(1-p_2)(1-P)a + (1-p_1)Pb + p_2(1-P)c$
4.	O_c	O_2	$Pb + (1-p_2)(1-P)c + (1-p_1)P$
5.	O_c	O_c	$Pb + (1-P)c$
6.	O_c	O_1	$p_2(1-P)a + p_1 Pb + (1-p_2)(1-P)c$
7.	O_2	O_c	$(1-p_1)Pb + p_2(1-P)c + p_1 P$
8.	O_2	O_1	$p_2(1-P)a + p_1 P$
9.	O_2	O_2	P

The strategy-seeking algorithm means the solution of inequalities expressing the relations between the average losses. In order to find a general solution first we formed these inequations for a pair by pair comparison of the nine strategies. The number of these inequations is *36* but there are *6* relations repeated three times which determine the optimum strategies without the other *18 relations. These 6* inequations and the key to the choice of the best strategy are demonstrated in *Table V*. This table is a generalization of *Table II* from the a priori case. For the general solution in case of the whole set of parameters all the *6* inequations are needed while in case of a given set of parameters four ineauations (not being determined in advance) are enough.

The benefit in average losses applying the optimum strategy as compared to any other one can be determined by subtracting the average losses presented in *Table IV*. Besides this absolute benefit the gain relative to the a priori one can also be analyzed (*MIKA, 1982*), but instead of further discussions concerning to these gains we turn to decision strategies in case of probabilistic forecasts.

Table V

The same as Table II but for assimilation of categorical forecasts. (See strategies 1.- 9. in Table IV)

	Inequalities	Strategies 1.	2.	3.	4.	5.	6.	7.	8.	9.
I.	$\frac{c}{1-b} < \frac{p_1 P}{(1-p_2)(1-P)}$	Ø	Ø	Ø	+	+	+	-	-	-
II.	$a < \frac{p_1 P}{(1-p_2)(1-P)}$	+	+	+	Ø	Ø	Ø	-	-	-
III.	$\frac{a-c}{b} < \frac{p_1 P}{(1-p_2)(1-P)}$	+	+	+	-	-	-	Ø	Ø	Ø
IV.	$\frac{c}{1-b} > \frac{(1-p_1)P}{p_2(1-P)}$	Ø	+	-	+	-	Ø	-	Ø	+
V.	$a > \frac{(1-p_1)P}{p_2(1-P)}$	-	+	Ø	+	Ø	-	Ø	-	+
VI.	$\frac{a-c}{b} > \frac{(1-p_1)P}{p_2(1-P)}$	-	Ø	+	Ø	+	-	+	-	Ø

3.2 Probabilistic forecasts

If the decision-maker can get the undistorted π_1 and $\pi_2 = 1 - \pi_1$ probabilities of weather conditions X_1 and X_2 there is no need for further information about the forecast-skill ie. no preliminary test-period is necessary. The scheme for constructing the decision strategy is also simple. An operation is joined to appropriate probability intervals in order to minimize the expected value of loss.

Rules for choice of the optimum strategy is now being derived in four steps. First we demonstrate that the number of intervals with different operations can not be more than three for the optimum strategy (*Step 1*). Than the number of strategy-types containing two or three intervals (ie. assuming that the best strategy can not be the one fixed operation) is being reduced to two (*Step 2*). As the third step we demonstrate that applying the compromizing operation between the two adequate ones we do not always get a better strategy (*Step 3*). At last the optimum turning points between the intervals with different operations are being calculated (*Step 4*).

Step 1. If there at least four such intervals than at least two disjunct ones would have the same operation joined to. We intend to prove first that it can not be an optimum strategy because in any point being right in the middle of the distance between two optional points from the two intervals with same operation the application of this operation (instead of the original one) would give a better result.

Let this point in the middle have a π probability and the two other points from the disjunct intervals with equal operation have $\pi - \Delta\pi$ and $\pi + \Delta\pi$. Let us also assume that in these two points there are operations O_1 joined to while in point π we have O_c. Of course this strictly limits the generality of the proof but the way to prove the statement is completely similar for all the six possible combinations of flanking. The statement that the O_1, O_c, O_1 flanking for points $\pi - \Delta\pi, \pi, \pi + \Delta\pi$ is the optimum means that the losses for flankings O_c, O_c, O_1 and O_1, Oc, O_c are higher, ie.

$$a(\pi - \Delta\pi) < [b(\pi - \Delta\pi) + c(1 - \pi + \Delta\pi)] \quad /11/$$

and

$$a(\pi + \Delta\pi) < [b(\pi + \Delta\pi) + c(1 - \pi - \Delta\pi)] \quad /12/$$

Summing up these two inequations we get

$$a\,\pi < [b\,\pi + c(1 - \pi)] \quad /13/$$

which means that putting operation O_1 instead of O_c into the point π a better strategy can be received.

In case of the other five possible combinations the terms are different on both sides of /11/ an /12/ but the $\Delta\pi$ increments disappear exactly in the same way and we get the necessary relation in point π similarly to /13/.

Principially repeating this change for all pairs of points taken from the original disjunct intervals with the same strategy we get either a new or a wider interval with the same operation. Anyhow the final result is one common interval with the same strategy containing the initial ones and the whole interregnum between them.

Step 2. So the maximum number of intervals with different operations in the optimum strategy is three which means *15* types of possible strategies so as *3* types containing one operation independently of the forecasted probability (ie. the a priori strategies), *6* types containing two and *6* types containing three operations in some sequence of forecasted probabilities. Furthermore the strategies where the natural order of O_1 and O_2 is disturbed ie. O_2 is joined to an interval with less π_2 can not be optimal and also those strategies can be excluded in which the compromizing operation is attributed to an interval with a probability higher than the interval with the adequate operation. We can aldo suppose that strategies with one fixed operation only can not be so effective than that of two or three operations joined to the appropriate intervals. In this way we can reduce the number of potentially optimal strategy types to four. These are $S_1 = (O_1, O_2)$, $S_2 = (O_1, O_c)$, $S_3 = (O_c, O_2)$ and $S_4 = (O_1, O_c, O_2)$.

However strategies S_2 and S_3 also can not be the optimum because joining O_2 to $\pi_2 = 1$ in S_2 and O_1 to $\pi_1 = 1$ in S_3 and also into their appropriate one-sided surroudings we get better strategies so that within these intervals an elementary loss greater than zero would have little probability (none in $\pi_2 = 1$ and $\pi_1 = 1$ respectively) instead of high probability of the finite non-zero loss in the compromizing operation.

Step 3. So the number of candidate-types *for being the optimum* is reduced two: $S_1 = (O_1, O_2)$ and $S_4 = (O_1, O_c, O_2)$. We demonstrate that the first type can also be optimal in the case of a possible relation between the type economical parameters. The first thing to prove is that having the best strategy of type S_1, an appropriate strategy of type S_4 can be better only if it does not join operation O_1 to any point where O_2 is the optimum in the best strategy of S_1. Surely in the opposite case *in* strategy S_4 we could join O_2 instead of O_1 to the sub-interval where it takes place in the optimum strategy of type S_1 getting a better strategy. However as it has been proven at the beginning of this point a strategy containing four intervals (ie. O_1, O_2, O_c, O_2 in our case) can not be the optimum.

Therefore we can reduce the question of optimity-condition to the following: What is the condition for the best strategy of type S_1 unable to being improved by inserting the operation O_c between the two adequate operations?

This inserted interval of O_c has to contain that point of the probability scale where the mean loss of operation O_1 is the same as of O_2. if supposing the interval with O_c devided one of the O_1 or O_2 intervals the number of intervals would be more than three and such a strategy could not be the optimum.

The average loss in the point where $L(O_1) = L(O_2)$ is

$$(1 - \pi_1)a = \pi_1 \qquad /14/$$

from where

$$\pi_1 = \frac{a}{1+a} \qquad /15/$$

using the loss-matrix of *Table Ic*. Inserting O_c into this point we get an average loss as high as

$$b\,\frac{1}{1+a} + c\left(1 - \frac{1}{1+a}\right) = \frac{b + ac}{1+a} \qquad /16/$$

The condition for this loss being lower than the initial one comparing the numerators of fractions in the right sides of /15/ and /16/ and deviding by a is

$$\frac{b}{a} + c < 1 \qquad /17/$$

which is not a straight consequence of the loss matrix set up in *Section 2*. So if /17/ is not fulfilled then the best strategy of type $S_1(O_1, O_2)$ can be more beneficial than any strategy of type $S_4(O_1, O_c, O_2)$.

Step 4. The turning point of the probability scale is determined by /15/ for the case if there is no better strategy in S_4. In the opposite case the optimity conditions are $L(O_1) = L(O_c)$ and $L(O_c) = L(O_2)$ concerning to the turning points (π_{1c} and π_{c2}) of the probability scale. This means

$$(1 - \pi_{1c})a = b\,\pi_{1c} + c(1 - \pi_{1c}) \qquad /18/$$

and

$$\pi_{c2} = b\,\pi_{c2} + c(1 - \pi_{c2}), \qquad /19/$$

which can easily be trandsformed to

$$\pi_{1c} = 1 - \frac{b}{a+b-c} \qquad /20/$$

$$\pi_{c2} = 1 - \frac{1-b}{1-b+c} \qquad /21/$$

Knowing the economical parameters of the decision problem one can assimilate the undistored probability forecast in the following way: Initiate operation O_1 when $\pi_1 > \pi_{1c}$, operation O_2 when $\pi_{c2} < \pi_1 < \pi_{1c}$ and operation O_2 when $\pi_1 < \pi_{c2}$.

The economical effect of the optimization by the probability forecasts depends on the frequency distribution of different (objective) output probabilities. Therefore it can not be expressed by simple subtractions as in case of categorical forecasts.

4. An example for the meteorological part of the decision-models

Formulae derived in *Sections* 2 and 3 are fairly general for the decision in a concrete situation ie. in case of three possible operations influenced by two alternative weather states. In order to help in their application easier we present an example which is based on macrosynoptic types derived by *PECZELY (1957, 1983)* for Hungary. Here we arbitrarily demonstrate the case of measurable precipitation in January at Budapest applying the necessary informations from *PECZELY (1961)*. (See *Table VI*)

Table VI

The probability of precipitation [π_2 (T_i)] in different (T_i) macrosynoptic types appearing with a $p(T_i)$ probability at Budapest in January and also their product asthe weight of each macrotype in climatic probability of precipitation

Péczely-types		$\pi_2(T_i)$ %	$p(T_i)$ %	$p(T_i)\,\pi_2(T_i)$ %
T_1	CMw	78	8.8	6.9
T_2	C	75	0.7	0.5
T_3	mCw	68	8.8	6.0
T_4	zC	61	7.0	4.3
T_5	CMc	45	2.4	1.1
T_6	mCc	43	4.0	1.7
T_7	Ae	39	13.7	5.3
T_8	AF	37	4.7	1.7
T_9	As	36	7.1	2.6
T_{10}	Aw	31	11.0	3.4
T_{11}	An	30	11.6	3.5
T_{12}	A	21	16.6	3.5
T_{13}	AB	19	3.6	0.7
Total			100.0	41.2

If we have only the a priori (climatic) information that is a general probability of precipitation (being $p = 41.2$ % in our case) we can choose the most beneficial standard operation by inequalities in *Table II*. Having a categorical forecast which in this case is equivalent to a definition of a P_{cut} probability and saying "precipitation will exist" if $\pi\ (T_i) > P_{cut}$ and vice versa. In this case we need a preliminary period to establish P_1 and P_2 if we do not know this P_{cut}. But knowing the forecaster's (standard) P_{cut} we can calculate the key parameters of the forecast as

$$p_1 = \frac{\sum\limits_{\pi(T_i) < P_{cut}} p(T_i)\,(1-\pi(T_i))}{1-P} \qquad /22/$$

$$p_2 = \frac{\sum\limits_{\pi(T_i) > P_{cut}} p(T_i)\,\pi(T_i)}{P} \qquad /23/$$

In *Figure 1* these forecast-skills are presented in function of P_{cut}. We can establish that increasing or decreasing of P_{cut} we can change p_1 and p_2 in the opposite direction. The optimum P_{cut} (which is equal to $1 - \pi_1$ from /15/ for probabilistic forecasts) strongly depends on the economical parameters. Having the key parameters of the forecast-skill the choice of the optimum strategy can be further accomplished applying inequalites of *Table V*.

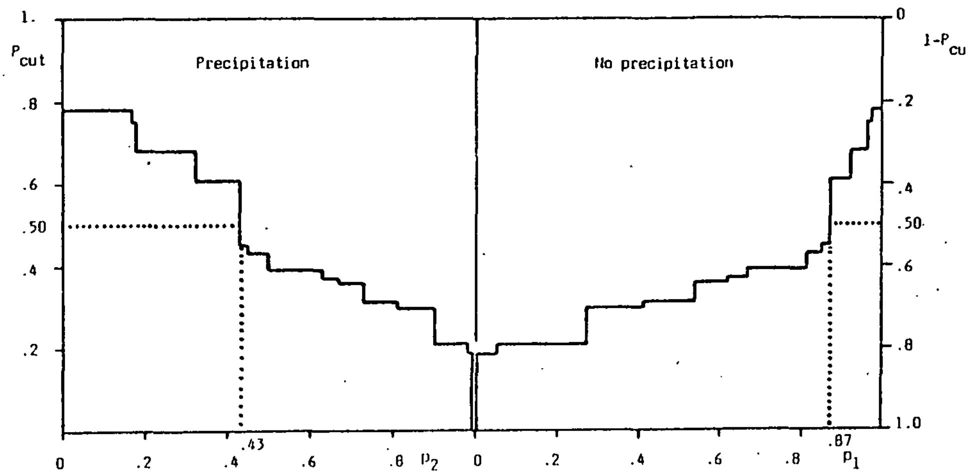

Fig. 1 The skill of two categorical statements as functions of the critical probability (P_{cut}) for saying "yes" (if $\pi_2 > P_{cut}$) or "no" ($\pi_2 < P_{cut}$). The arbitrary P_{cut} = 0.50 illustrates the asymmetry of P_1 and P_2. Here P_2 belongs to the existence of precipitation. For further information see Table IV.

In case of probabilistic forecasts the formulae /15/ or /20/ and /21/ (depending on logical value of /17/ dictate the optimum strategy while the necessary probabilities can be calculated on the base of *Table VI* by grouping the terms for which $\pi(T_i)$ are adequate to probability intervals of the different operations. In these examples we can also see that the most efficient information on weather is the probabilistic forecast which allows the application of all the three operations or if the two-operation variant is the optimum its turning points are chosen as the most beneficial. In case of categorical forecats maximum two operations can be applied as a function of forecasted staatement and its turning point of the probability scale (P_{cut}) is chosen arbitrarily by the forecasters ie. independently of the decision problem. The less beneficial tool in this context is of course the climatic probability alone which allows one single operation not applying any supplemental real-time information.

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